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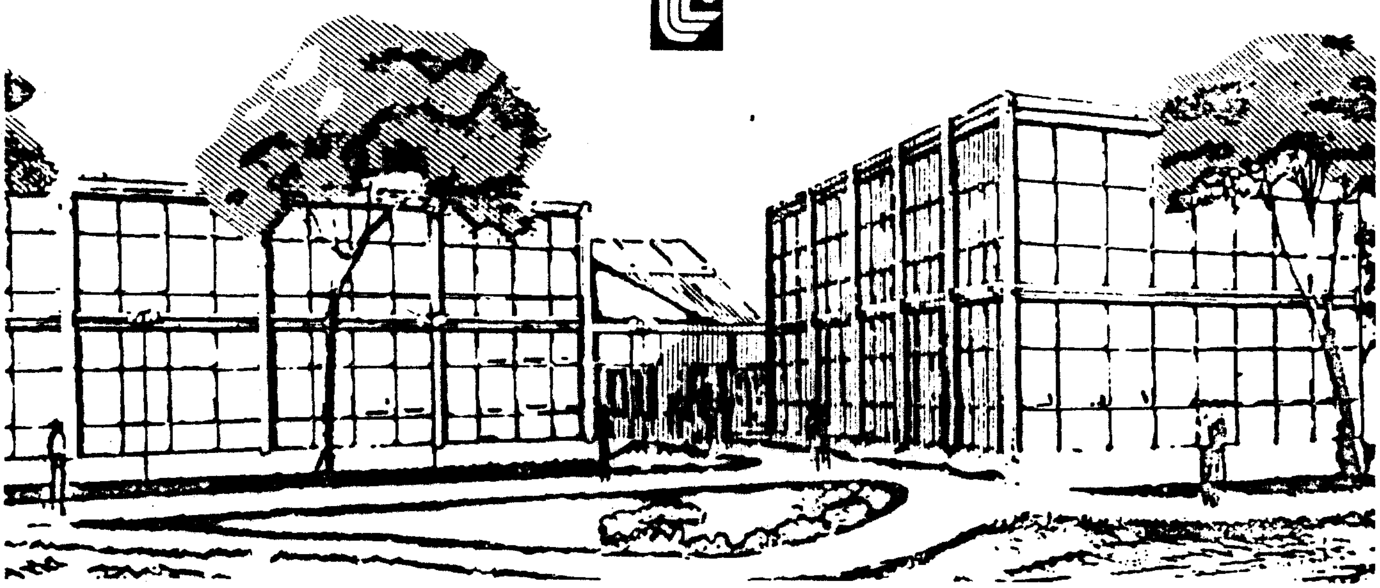

METHODOLOGY FOR ESTIMATING ACCIDENTAL RADIOACTIVE RELEASES IN NUCLEAR WASTE MANAGEMENT

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The estimation of radioactive release functions is a necessary step in the evaluation of radiological risks attendant to any waste management system or subsystem. The amount of a radioactive nuclide and the manner in which it is released under a given set of conditions serve as part of the input data to the subsequent transport, demographic, and dosage models. The result of these model calculations gives a measure of the consequence of the release. This measure may be some dosage rate, or the number of expected fatalities, or some other measurable effect on society. In this context the radiological risk associated with a release is defined as the product of the consequence of that release and the probability of that release occurring. Expressed in equation form the risk is

$$\text{Risk} \equiv \text{Consequence} \bullet \text{Probability (of consequence occurring).}$$

A convenient manner of presenting the measure of risk of a system or subsystem is by means of a risk curve (1-3). The probabilities of all incidents leading to consequences that equal or exceed a certain value are summed or integrated and this overall probability is plotted against that value of the consequence. In mathematical terms $P(Q>q)$ is plotted against q; where q is a chosen value of the consequence, and $P(Q>q)$ is the overall probability for the system that the consequence equals or exceeds q. Sometimes frequencies instead of probabilities are plotted against the value of the consequence. That is all right as long as one remembers which one is being used when making comparisons or estimating expected values. In order to evaluate radiological risk, therefore, it is necessary to have estimates both of the radioactive release and the probability or frequency of its occurrence.

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Radioactive releases may be classified according to the mechanism of release into three different types: 1) dissolution by natural waters, 2) vaporization, and 3) dispersion into the air as fine particles. It is fairly obvious that the release of the same amount of radioactivity of different nuclides could result in different dosages since either the nature of their radiations, their half-lives, or their chemistries are likely to be different. However, a unit of radioactivity of the same nuclide released by each of the above three mechanisms would probably result in three different dosages because of the different pathways followed to and through the biosphere. Each type of release would have a different factor relating amount released to dosage for a unit release of the same nuclide. Therefore, in considering an accidental release of radioactivity one must not only consider the amount of each nuclide released but also the relative amounts of each nuclide that may be released by the different mechanisms.

As a general rule, one cannot always expect to decouple the release function model from the transport, demographic, and dosage models. However, for a small enough subsystem this can be possible, and for discussion purposes here we can consider the release of a particular nuclide by a particular mechanism as being directly proportional to the final consequence of that release.

In order to elucidate the methodology we will consider a simple model consisting of a radioactive waste form enclosed in a barrier system. This system is subjected to a certain type of accident that may result in a radioactive release. For simplicity we will consider just the release of a single nuclide by one mechanism. Let x represent a vector variable, the elements of which are values of parameters for the conditions of the accident that affect the release. The frequency density function for this type of accident is given by $f(x)$. In actuality, statistics on frequencies of accidents can rarely be found where x represents more than one, or at most two joint parameters. Therefore, again for simplicity, we will choose x to be some single parameter that serves as a measure of the "severity" of the accident. We will also work here with fractional releases, as the total source term will vary in practice.

The waste form serves as a source term. Let s represent the fraction of the nuclide that would be released from the source if there was no barrier system. For a given value of x there will, in general, be a distribution of values for s. The conditional probability density function for the fractional release from the source, s, for a given x can be expressed as $p(s|x)$. (The less complete the description of the conditions of the accident provided by x, the broader the distributions of s are likely to be.)

For each value of x, there will be some fraction of times that the barrier system is breached, b(x). In other words, b(x) is the probability of breaching the barrier for a given x. There will likely be some threshold value of x for b(x). The function b(x) will then increase monotonically as x increases until it reaches a value of one or approaches one asymptotically.

If the barrier system is breached, some fraction of that radioactivity that was released from the waste form will pass through the barrier. If this fraction is designated as r, then for each value of x there will be a distribution of values of r. The conditional probability density function of r will be given by $p(r|x)$.

The overall fractional release from the system t, assuming a barrier breach, is equal to the product of r and s, or

$$t = r \cdot s.$$

We need now to generate the function $P(T>t)$, the probability that the overall fractional release equals or exceeds the value of t, so that we may plot $P(T>t)$ versus t. We may obtain our desired results by using extensions of the following relationships involving probability density functions, remembering that r, s, and t all have limited ranges extending from 0 to 1.

$$p(t)dt = \int_x p(t,x)dtdx$$

$$p(t,x)dtdx = p(t|x) \cdot p(x)dtdx$$

$$P(T>t|x) = \int_t^1 p(t|x)dt$$

$$P(T>t) = \int_t^1 p(t)dt = \int_x P(T>t|x) \cdot p(x)dtdx$$

To obtain $P(T>t|x)$ we first consider the probability distribution function of a random variable that is the product of two other random variables:

$$z = u \cdot v$$

Where $p(u)$ and $p(v)$ are continuous from 0 to ∞, the cumulative probability distribution of z is given by:

$$P(Z<z) = \int_0^{\infty} p(u)\left(\int_0^{z/u} p(v)dv\right)du$$

In the case where u, v, and z are all limited to the range from zero to one

$$P(Z<z) = \int_0^1 p(u)\left(\int_0^{z/u} p(v)dv\right)du, \qquad z/u \leq 1$$

and

$$P(Z>z) = 1 - P(Z<z) = \int_0^1 p(u)\left(\int_{z/u}^1 p(v)dv\right)du, \qquad z/u \leq 1$$

where the integrals with respect to v are evaluated only for values of $z/u < 1$. Since t is also a product of two random variables r and s, we can use a similar treatment to obtain $P(T>t|x)$. If we remember that r is the fractional release through the barrier assuming a breach, and that $b(x)$ represents the probability that the barrier system will be breached, we may write

$$P(T>t|x) = \int_0^1 p(r|x)\left(\int_{t/r}^1 p(s|x)ds\right)dr \cdot b(x), \qquad t/r \leq 1$$

and

$$P(T>t) = \int_x \left[\int_0^1 p(r|x)\left(\int_{t/r}^1 p(s|x)ds\right)dr \cdot b(x)\right] \cdot p(x)dx, \qquad t/r \leq 1$$

where the inner integral is evaluated only for $t/r < 1$, and the expression in the square brackets is integrated over all values of x.

Usually one knows very little about $p(r|x)$ and $p(s|x)$. However, it is generally much easier to estimate expectation values of r and s as a function of x. If we consider the distributions of r and s as being concentrated at the expectation values, then $t(x) = r(x) \cdot s(x)$ and

$$P(T>t) = \int_{x}^{\infty} b(x) \cdot p(x)\, dx$$

This treatment underestimates the probabilities of the extreme low and extreme high values of t while still leading to the same overall expectation value for the risk. In order to be able to plot frequency rather than probability that a consequence exceeds a certain value the frequency of x rather than the probability of x should be used in the above expressions.

For volatilization and dissolution, although both are complex and different phenomena, the expected values of s(x) are likely to be describable by an expression that is the sum of terms of the form

$$A\tau^{n} \exp - B/\Theta$$

where τ is the time the exposed waste form is at an absolute temperature of Θ, B is dependent on the chemical and physical form of the nuclide, and A depends on the other conditions of the release. If the mechanism is diffusion controlled, n is of the order 0.5. If the mechanism is surface controlled, n is of the order of one. For dispersion, the expected values of s(x) depend on such things as the amount of fine particles present after the accident, the size of the breach and its proximity to the fine particles, and the driving forces for dispersion.

When estimates of s(x) are obtainable, it is sometimes possible to make reasonable assumptions about $p(s|x)$. At other times, one may be able to estimate a maximum credible value for t, and thus may be able to define a limit for a plot of $P(T>t)$ vs. t. The handling of each case should be decided on the merits of the nature of the available data.

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